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A STOCHASTIC MODEL TO PREDICT RADIO INTERFERENCE CAUSED BY CORONA ON HIGH VOLTAGE TRANSMISSION SYSTEMS

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ABSTRACT

A stochastic model to predict radio interference field as caused by corona discharges on high voltage transmission lines has been developed. This model is based on corona discharge distributed randomly in time and space.

A stochastic model for the corona current induced by corona discharges on power lines is proposed. On the basis of the proposed corona current model, a rigorous analysis is presented to evaluate the radio interference (RI) field caused by corona discharges on a single conductor using the stochastic method.

INTRODUCTION

Radio interference, generated by corona discharges, is caused by the movement of the space charges in the electric field in the vicinity of conductor surfaces of high voltage transmission lines. The corona discharges are due to a high electric field in the vicinity of the conductor [1,2].

Corona sources are known to be random both in magnitude and repetition time [1,3-8]. In most cases, the corona currents injected into the conductor surface of a transmission line have been represented by the spectral density to deal with the randomness of the corona generation. To simplify the analysis, corona generation has also been assumed to be uniform along the line and represented by a constant value [1,2,7,9,10].

However, spectral density of corona generartion has meaning only when the corona generation has the property at least wide-sense stationarity. Therefore, without developing the statistical model for corona generation, the power spectral representation for corona current would be incomplete and probably inaccurate. In this connection, physical and analytical models of these corona processes appear necessary.

The purpose of this study is to determine the statistical nature of RI generation, propagation, and reception.

CONSTRUCTION OF THE MODEL OF THE STOCHASTIC RI ANALYSIS

The principal stages in the construction of the stochastic model to predict radio interference caused by corona discharges can be accomplished in several steps. The intent here is to provide a general overview without developing a detailed analytical structure.

The first step is to construct a stochastic model for corona current. Let $J(z,t)$, $0 \leq z \leq L$, $-\infty < t < \infty$, be the corona current at time t and at position z along the line of length L, where z is the axis of the transmission line. At a specific location (z,t), $J(z,t)$ denotes the random current with a scalar value. Thus $J(z,t)$ is a stochastic process considered as a family of random variables.

The collective outcome of all the experiments comprising random process $J(z,t)$ is denoted by $J^{(j)}(z,t)$, the realization of the stochastic process $J(z,t)$. At a given time t_0, $J(z,t_0)$ is a stochastic process and denotes the corona current distribution along the line. In most cases, $J(z,t_0)$ can be considered as a process having a Poisson distribution.

At a given point z_0, $J(z_0,t)$ $-\infty < t < \infty$, is a stochastic process in time with a value in $R = (-\infty, \infty)$ and denotes the pulse trains. The shape and repetition rate of corona pulse is constituted of random parameters that allow us to treat a variety of corona sources that may be operating concurrently but may arise from different mechanisms.

With this way, a stochastic model for corona current can be constructed. The next step is to construct a transmission line equation that relates the induced noise voltage to corona current. If T is the general operator representing the transmission line equation, the noise voltage can be related to corona current as follows:

For many applications, Fourier transform turns out to be the appropriate device for treating the steady-state conditions. It can be shown that any aperiodic random disturbance, such as the corona, does not possess the Fourier transform in the usual sense. In order to circumvent this difficulty, consider $J^{(j)}(z,t)_T$, which is obtained from a member function of the ensemble $J(z,t), -\infty < t < \infty$ by truncation so that $J_T{}^{(j)}(z,t)$ vanishes everywhere outside (-T/2, T/2). In this case, there usually exists the Fourier transform of $J_T(j)$. On the basis of this broadened concept of spectrum, the average power density of random process is represented by the power spectral density. The power spectral density is defined by the time average of mean square spectrum of a stochastic process. It, by definition, is a property of the ensemble as a whole.

Let us consider a single corona source, $J^{(j)}(z,z_n,t)_T$, injected into a point $z = z_n$ on the transform on both sides of Eq. (1), we have for this single source

$$T(W)\quad [v^{(j)}(z,z_n,w)_T] = J^{(j)}(z,z_n,w)_T \tag{2}$$

The solution of Eq. (2) yields the noise $v^{(j)}(z,z_n,w)$ at a point z induced by a single corona source at $z = z_n$.

Having obtained the voltage $v^{(j)}(z,z_n,w)$ for a single corona source, the problem with a general source distribution can be obtained with a superposition. The noise voltage for the multiple corona sources can therefore be represented by

$$v^{(j)}(z,w) = \sum_{n=1}^{n} v^{(j)}(z,z_n,w) \tag{3}$$

Where N is the Poisson process denoting the number of corona events per unit length along the line.

The next step is to evaluate the ensemble property of $v(j)(z,w)_T$. The power spectral density of v is defined by

$$W_v(z,\omega) = \lim_{T\to\infty} 2/T\ \overline{|v^{(j)}(z,\omega)|^2}$$

By suitable attention to the form and the statistical structure of the interfering noise source, the power spectral density of the noise voltage can be determined.

The noise voltage v(z,w) on the line induces electric field around the line. If the electric field is assumed to be related to the voltage by an operator L as follows:

$$L[E(x,y,z,w)] = v(z,w)$$

Then the power spectral density $W_E(x,y,z,w)$ of E can be determined.

The electric field in the region adjacent to the antenna of a radio receiver induces a voltage in the antenna. This is an interference voltage or noise signal. Let Y(w) be the overall transmission function of the mixer and i-f section of the receiver. The electric field at the output of the receiver is given by

$$W_e(x,y,z,\omega) = |Y(\omega)|^2\ W_E(x,y,z,\omega)$$

Then the ensemble average of the square electric field is given by

$$e(x,y,z,t)^2 = \int_0^\infty |Y(\omega)|^2\ W_E(x,y,z,\omega_0 + \omega')df'$$

If it is assumed that the output noise signal is ergodic, the mean square value of the output is the same as the time average of the square of any member of the output ensemble e(x,y,z,t).

Thus, in the extension of the familiar nonstatistical treatment of a deterministic noise signal in the time and frequency domains, we can construct analogous relations in the case of the ensemble and its representative members.

RESULTS

A single-circuit horizontal line shown in Fig. 1. is considered for the RI field calculation. The maximum system voltage is 362 kv. The basic geometry is chosen as average values presently used for EHV transmission lines [11].

Effect of the Terminating Impedances of the Line

Table 1 shows the radio interference levels for different line terminations. Four terminations.are considered for two different line lengths.

Effect of the Mean Number of Corona Events

Figure 2 shows the RI field variation along . The RI fields were calculated for the lateral distance of 15m from the outer conductor.

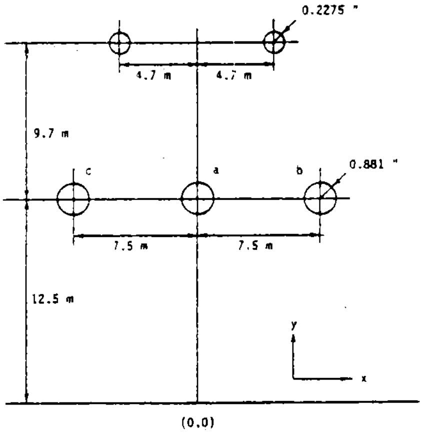

Fig. 1. Single-circuit horizontal line configuration, 345 kV.

Table 1. The Effect of Line Terminations on the RI Field

Z_A and Z_B are the termination impedances of line AB from each conductor and ground. L denotes the total length of line. RI field is the quasi-peak value calculated at 1 MHz and 5 KHz bandwidth. The mean number of corona events per meter is assumed to be 1. Terminal impedance -j39.79 represents a coupled capacitor 4000 pF.

Terminal Impedances		RI Field (dB above μv/m)	
$Z_A(\Omega)$	$Z_B(\Omega)$	L = 10 m	L = 1600 m
10^{10}	10^{10}	82.860	82.860
10^{10}	-j39.79	69.290	83.162
0.0	0.0	82.285	81.028
-j39.79	-j39.79	82.285	82.530
matched	matched	82.285	82.530

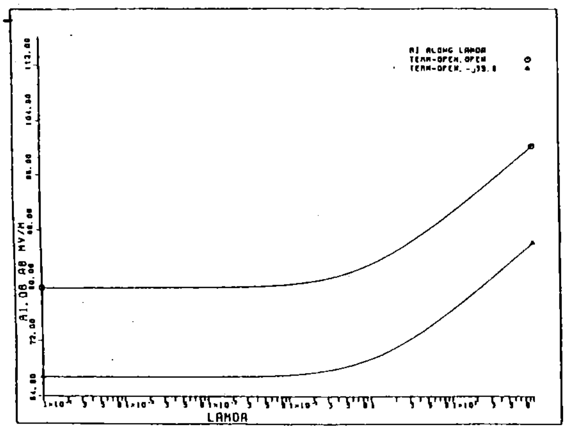

Fig. 2. The effect of λ on the RI field.

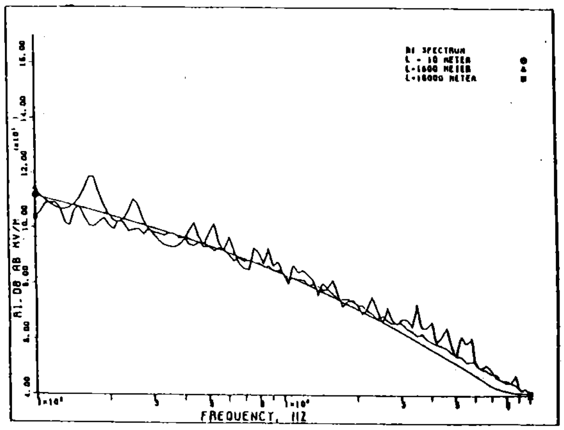

Fig. 3. RI Field spectrum for different line length, λ = 1.

RI Frequency Spectrum

The frequency spectrums were calculated over the range from 0.1 to 10 MHz at the center of the open-ended line at both ends. In order to see the effects of line length and the number of corona events on the RI spectrum, the RI fields were calculated for three cases of line length at each frequency from 0.1 to 10 MHz. Calculated RI fields are shown in Fig. 3.

CONCLUSIONS

A comprehensive and rigorous analysis has been presented in the research of a stochastic model to predict radio interference caused by corona on high voltage transmission systems. The analysis presented makes the following principal contributions:

1. A stochastic model of the corona current injected into the high voltage power transmission line has been proposed.
2. A rigorous analysis is developed for the derivation of a stochastic transmission line equation. The solution of a developed stochastic transmission line equation with the influence of l line terminations is obtained from rigorous and comprehensive analyses.
3. The power spectral density of interference voltage caused by corona is obtained by a rigorous stochastic analysis.
4. The radio interference field strength at the radio receiver located near the line is developed by using the Wiener-Khintchine theorem.

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